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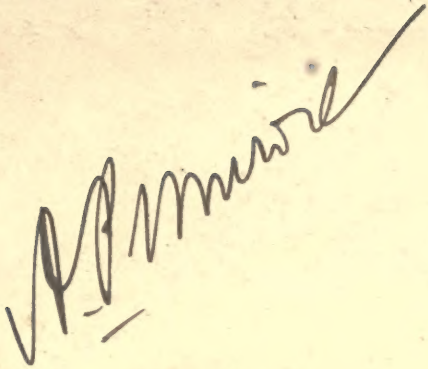

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SUTURE OF ARTERIES

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SUTURE OF ARTERIES

An Experimental Research

By
E. ARCHIBALD SMITH
M.B., CH.B., VICTORIA UNIVERSITY
F.R.C.S., ENGLAND

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LONDON
HENRY FROWDE HODDER & STOUGHTON
OXFORD UNIVERSITY PRESS WARWICK SQUARE, E.C.
1909

PREFACE

THE research described in this little book was undertaken in Vienna, and has been accepted for publication by Langenbeck's *Archiv.* My excuse for issuing it in book form in England is, that very little literature on the subject is available in our language, and that almost entirely in American journals.

The revival of the procedure of suture of arteries is due to German surgery, and nearly all recent research on the matter has been done by Continental and American workers. It was however first suggested by an English surgeon, and first carried into effect by one of his colleagues with brilliant results.

For the convenience of any taking more than a passing interest in the subject, I have appended a list of references to previous literature, which I have endeavoured to make as complete as possible, including both articles dealing with experimental research, and those describing clinical observations.

February, 1909.

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SUTURE OF ARTERIES

SECTION I

THE origin of the idea of suturing a wounded artery, with retention of its lumen, instead of ligaturing it, is certainly to be attributed to Lambert, a surgeon of Newcastle-upon-Tyne in the middle of the eighteenth century.

The following letter, written by Lambert to Hunter, and read by him on June 15, 1761, is of great interest in this connexion—

"The case of the aneurysm was indeed curious, and, I am in hopes, will prove useful; but I must not be too sanguine in its favour, till I have seen the effects of such an operation confirmed by several instances; till then, I would not be fond of saying anything of it in print except you think that, as few of these injuries fall to any single man's share in the ordinary course of business, it would, by that means, afford a larger field to put others upon the trial, so as to introduce the method sooner.

"If this be your opinion, I have no objection

to your giving any short account of it you may think proper. The history was thus:

"I had very carefully attended to the cure of three aneurysms, for which operation was performed by my late worthy friend and colleague, Mr. Hallowell.

"In one of them, after the operation was performed in the common way, by a ligature above and below the aperture in the artery, such violent pain, swelling, and inflammation came on as to threaten a gangrene. Bleedings, fomentations, poultices, etc., mitigated these symptoms; a plentiful suppuration ensued; the wound gradually healed, and the patient was discharged from the hospital with a weak arm, and a pulse much weaker in that wrist than in the other.

"This case, in particular, made me turn my mind to the operation for the aneurysm, and made me wish to see it done with some alteration in the method, so as to make less disturbance in the circulation of the part. I recollected all that I had seen or read of the effects of styptics, of pressure, and of ligatures in the case of hæmorrhage. I considered the coats and motions of arteries, and compared their wounds with the wounds of veins, and other parts. I reflected upon the process of nature in the cure of wounds in general, and considered, in particular, how the union of divided parts was brought about in the operation

of the hare-lip, and in horses' necks that are bled by farriers. Upon the whole, I was in hopes that a suture of the wound in the artery might be successful; and if so, it would certainly be preferable to tying up the trunk of the vessel.

"I communicated my thoughts to Mr. Hallowell, Mr. Keenlyside, and some other friends of the profession.

"A case of aneurysm from bleeding occurred, and fell to Mr. Hallowell's lot. I recommended the method I have hinted. He put it in execution, June 15, 1759. Everything was done in the usual method till the artery was discovered; and the tourniquet being now slackened, the gush of blood shewed there was no deception.

"Next, two ligatures, one above the orifice and one below, were passed under the artery, that they might be ready to be tied at any time, in case the method proposed should fail. Then a small steel pin, rather more than a quarter of an inch long, was passed through the two lips of the wound in the artery, and secured by twisting a thread round it, as in hare-lip. This was found to stop the bleeding, upon which the arm was bound up, the patient put to bed, and ordered to be kept quiet, etc., as usual in such cases.

"The wound was first dressed on the fourth day, viz., June 18. It looked well for the time, and continued to heal without interruption in a

kindly manner. The pin came away with the dressings June 29, that is, on the fourteenth day; and on July 7 every part was healed except what was kept open by the two ligatures, which remained loose in the flesh like two setons. These were therefore removed. In a few days after this the wound was completely cicatrised; and July 19 the patient was discharged from the hospital perfectly well, and with a pulse in that arm nearly as strong as in the other. Indeed, the pulse was very little altered immediately after the operation: it was weakened in a small degree, as might be expected from the diameter of the vessel being straightened; but it was so strong and equal that we had not the least doubt of the blood's continuing to circulate freely through it.

"If it should be found by experience that a large artery, when wounded, may be healed up by this kind of suture without becoming impervious, it would be an important discovery in surgery. It would make the operation for the aneurysm still more successful in the arm when the main trunk is wounded, and by this method, perhaps, we might be able to cure the wounds of some arteries that would otherwise require amputation or be altogether incurable."

In 1772, ASSMANN, of Gröningen, did some unsuccessful experiments on dogs, and expressed the opinion that the operation was not feasible.

So far as can be traced, this opinion was re-echoed and held good up to the early eighties of the last century.

Gluck, one of the first to revive the idea, made a series of nineteen experiments in 1881. He found a great tendency on the part of the suture material to cut through the vessel wall. He therefore devised a small ivory clamp, with which he closed the wound in the vessel, leaving the clamp *in situ*. With this apparatus he had some success.

In 1888, von Horoch, in his experiments, managed to obviate the danger of hæmorrhage at the time of, and after, the operation, but met with thrombosis in all his cases. As suture material he tried both catgut and silk, and used round curved needles.

He concluded that, as the closure of the vessel through thrombosis is a gradual process, time is given for the formation of a collateral circulation.

In 1889, Jassinowsky demonstrated that it was possible, by means of suture, to close wounds in blood vessels without fear of hæmorrhage, and with retention of the lumen. His experiments were twenty-six in number, on dogs, calves, and horses.

Three dogs died; one in narcosis, two of suppuration—all abdominal cases. One calf had an abscess in the wall of the aorta, but no thrombosis, thirty days after operation.

In another, forty-five days after operation the aorta was clear, perfectly healed, and not narrowed.

Of twenty-one operations on the carotid artery, there were:—

Twelve longitudinal wounds 3 mm. to 2 cm. long.
Two oblique wounds.
One tongue shaped, 2 to 4 mm.
One transverse, $\frac{1}{3}$ circumference.
Five transverse, $\frac{1}{2}$ circumference.
Four of these failed, but in no case was there hæmorrhage, merely a firm unyielding scar.

He used fine slightly curved needles and finest silk, and sutured only the two outer coats of the vessels. The sutures were interrupted, 1 mm. apart, with ordinary double knot. The vessel sheath was united over it.

He concluded that the necessary conditions of success were: (1) Complete asepsis. (2) Smooth edges to the wound in the vessel. (3) Suture not to penetrate the intima. He considered that all longitudinal wounds, and transverse ones of not more than half the circumference of a vessel, might be united, but that the operation was inadmissible in cases of very deeply placed vessels owing to difficulties of technique.

It may be considered that this research of

Jassinowsky's first demonstrated the feasibility of artery suture.

In 1897 and 1898 SILBERBERG did an extensive research on similar lines to Jassinowsky's; but he considered it immaterial whether the silk penetrated the intima or not, provided that it does not project into the vessel lumen. He generally used the continuous suture. His conclusions were otherwise similar to Jassinowsky's.

DÖRFLER did his experiments on large dogs. In twelve cases he pierced the whole thickness of the vessel wall, in four only the two outer coats. The first two cases failed owing to thrombosis, the remaining fourteen all succeeded. He used finest silk, and straight round needles; and made longitudinal, oblique, transverse, and flap wounds.

JIANU has used a suture impregnated with vaseline in his experiments upon suture of wounds in the abdominal aorta of dogs, sometimes with success. Thrombosis he attributes to injury to the intima.

Since SCHEDE first advocated the use of the suture in wounds of veins, this has become a recognized surgical procedure. The suture of wounds in arteries, however, is a later development, but a considerable number of cases performed clinically is now on record. The following were collected by Jensen up to 1903:—

Femoral . .	Zœge-Mauteuffel.
	Lindner.
	Ssabanjeff.
Common Iliac .	Israel.
Popliteal . .	Orlow.
	Garré.
Carotid, Brachial .	Heidenhain.
Axillary . .	Djemil Pasha.

to which I have, in addition, been able to discover the following:—

Popliteal . .	Morris.
	Körte.
	Le Fort.
External Iliac .	Wiart.
Brachial . .	Torbance.
	Glaumer.
	da Gäetano.
	Eichel.
Femoral . .	Swiatecki.
	Martin.
Carotid . .	Launy.
Axillary . .	Polnaru Caplescu.

Ssabanjeff and Orlow had subsequent opportunities of examining the vessel, and in each case found it patent, but somewhat narrowed.

SECTION II

End to End Union.—The first experiments made with the view of uniting a completely divided artery were done by Abbé, an American surgeon. Of ten attempts only one was examined later, and complete thrombosis was the result.

His method consisted in inserting an hour-glass-shaped glass tube into the two ends of the divided vessel, which were fastened over it with a ligature. The immediate result was restoration of the circulation. His experiments were made on the common carotid of sheep and the abdominal aorta of cats ; one of the latter, which recovered from the operation, was later exhibited to prove the success of the method. It is incredible that success could ultimately follow this method, or any where an endo-vasal support is used, and the cat in question must have recovered with the establishment of an efficient collateral circulation.

The subsequent methods of circular union which have been devised fall into two main categories, namely, suture and the use of a mechanical apparatus.

A variety of the latter have been devised, and will be later mentioned. Of the suture methods, according to the views held by the

experimenter in question, the suture is made to pierce all the coats of the vessel, or only the media and adventitia. Special modifications of the suture method are *Gluck's Cuff Method*, and *Murphy's Invagination Method.*

Gluck's Cuff Method.—The vessel is first laid free and clamped between rubber-covered

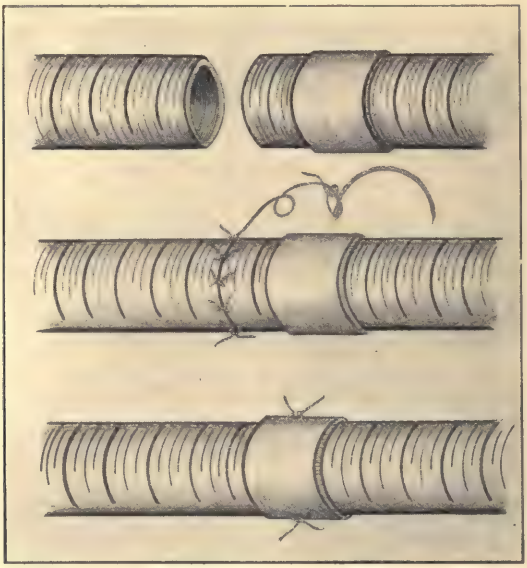


Fig. I.—Gluck's " Cuff " Method of End-to-end Union.
From above down—
1. Cuff formed, and laid over one end. 2. Ends of vessel sutured together.
3. Cuff in situ and suture completed.

forceps. A short length of the vessel is resected and laid like a cuff over one of the free ends. The two ends are then united by about eight interrupted sutures, involving the media

and adventitia only; six of the sutures are cut short, two on opposite sides of the vessel being left long, and armed with intestinal needles. The resected piece of vessel is now slipped over the sutured wound, and fastened in position by these two sutures.

Instead of a piece of the same artery, the "cuff" can be made of decalcified bone, thin gutta-percha, or a piece of artery or vein from the same or another animal.

The cuff is intended to bring slight pressure to bear on the suture line, thus aiding in preventing hæmorrhage, and making fewer sutures necessary.

No detailed results have been published.

Later, various attempts have been made to devise a suture which shall not project into the lumen of the vessel.

Brieau and Jaboulay devised the so-called U suture. They inserted the suture in the following way: From without inwards through all the coats of the vessel on one of the divided ends, then from within outwards at a corresponding point on the other end; the same suture was then taken at a distance of about one millimetre, through the two ends in the same manner but reverse order, so as to come out again one millimetre from where it was originally inserted, and there tied. The suture, in its course through the walls of the artery, has before tying the form of the letter U. The

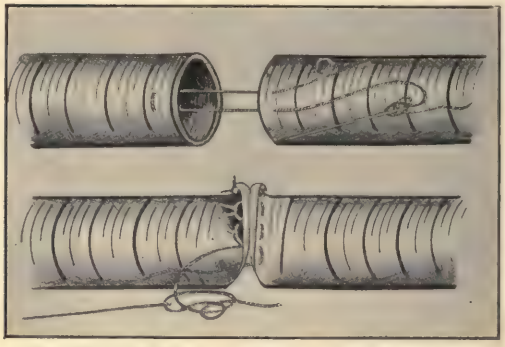


FIG. II.—U-Suture of Brieau and Jaboulay.
1. One suture passed, showing its U-shape.
2. Some sutures tied.

effect when tied is to bring the intima of one end against the intima of the other, and cause an eversion of the margin of both ends of the divided vessel.

The sutures are interrupted and about one millimetre apart, and it is stated that there is no fear of hæmorrhage after insertion.

The first ten attempts on dogs all thrombosed; the eleventh, on a donkey, succeeded.

SALAMONI independently devised the same suture, and tried it on the abdominal aorta of a dog with success, there being, three weeks later, no narrowing or thrombosis.

MURPHY has elaborated the Invagination Method. The procedure is as follows: Three sutures are passed at about equidistant intervals through the outer and middle coats of the central end of the divided artery, both ends being left long and untied. Each of the two ends of

each suture is then passed through all the coats of the peripheral end from within outwards, in corresponding positions to those where they are attached on the central end. When the sutures are drawn tight, the central end is invaginated into the peripheral. In order to facilitate the invagination, a longitudinal slit is made in the peripheral end, and this is after-

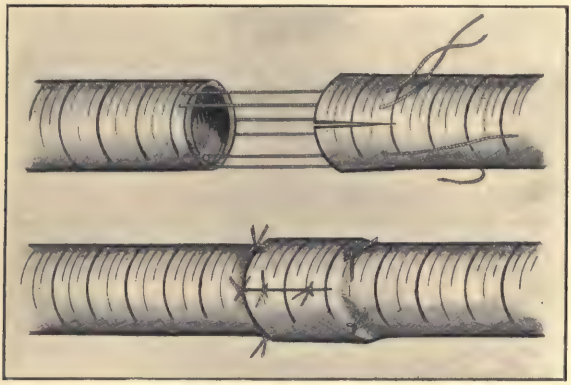


FIG. III.—Murphy's Method of End-to-end Suture by Invagination.
1. Three first sutures laid. 2. The suture completed.

wards closed by a suture, two or three of which are also inserted to attach the margin of the peripheral end to the outside of the central invaginating end, between the positions of the other sutures first inserted.

Experimentally Murphy did this operation thirteen times, three times successfully. The examinations were made at periods of eight days to five weeks after the operation. The

animals were dogs (carotid and femoral) and sheep (carotid), the successful cases being done on dogs, with, however, much narrowing of the lumen.

Dörfler, using Murphy's Method, did four operations on dogs. Three thrombosed, and the fourth only survived the operation three days, dying from hæmorrhage from another operation on a vein.

Bouglé using Murphy's Method, always met with thrombosis. He devised a modified invagination method of his own with a shorter invagination, and had some success after several failures.

Payr has endeavoured to find a method of uniting divided blood vessels by means of a mechanical appliance.

He chose magnesium in the pure metallic state as the material out of which his appliance was made, it being absorbed in the course of three or four weeks by the tissues.

He made small cylinders of $\frac{1}{3}$ to 1 cm. in length, on the outer side of which is a groove, near to one end, $\frac{1}{3}$ to $\frac{2}{3}$ mm. deep, the cylinder itself being of a diameter suitable for the vessel to be operated upon.

After division of the vessel between clamps, the central end of the divided vessel is drawn through the tube, the groove on which is nearer the free end of the vessel, and its free margin is reflected over the end of the cylinder, so that

the intima lies outwards, and there fixed by means of a fine silk ligature which is tied tightly round over the groove; the central end so treated is then invaginated into the peripheral end of the divided vessel. If any difficulty occurs in performing this manœuvre, it is re-

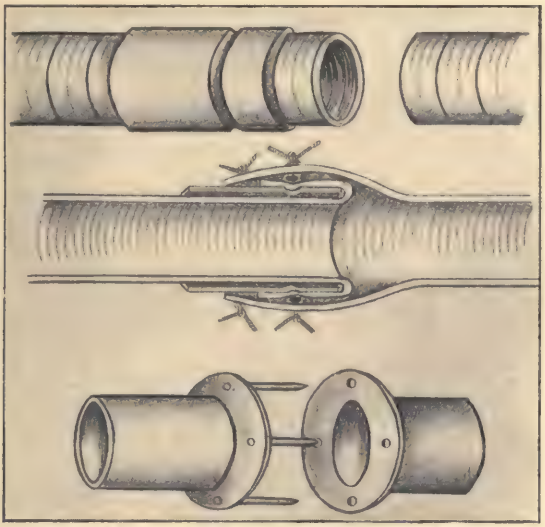


FIG. IV.—Payr's Methods of End-to-end Union.

1. The first apparatus.
2. The same, in longitudinal section, showing position of ligatures.
3. Payr's second apparatus.

commended to dilate the peripheral end somewhat. This being done, ligature number two is laid around the peripheral end of the vessel in a position exactly over the first ligature in the groove on the cylinder; or, the artery end may be so far drawn over the reflected piece of the central end as to lie on the bare part of the

cylinder and there be ligatured ; or two ligatures may be laid ; or sutures may be added as well as ligatures, but only piercing the adventitia. Sutures or a second ligature Payr considers superfluous.

He has tried the method on the carotids of dogs and pigs, and claims for it ease and quickness of applicability, and very good results. He states that the contiguous layers of the intima soon stick together, and the intima at the point of union is thickened, the distinguishing line between the two parts of the vessel being gradually obliterated, and the artery becomes embedded in dense connective tissue and adherent to the surrounding structures.

Payr has also devised another apparatus, which consists of two cylinders of magnesium, each $\frac{1}{2}$ to 1 cm. long, and each fitted at one end with a flange. On the flange of one, the male, are four spines of magnesium, and on that of the other, the female, four perforations in positions corresponding to the spines. The male piece is slipped over one end of the divided vessel, the wall of which at four equidistant places is impaled on the spines, the female piece over the other end, its wall being attached to the four holes by sutures. The two pieces are then brought together, the spines piercing the holes, and tightly clamped by bending the spines over. In this way intima is brought into contact with intima.

No detailed results are published of the use of the first apparatus, and no cases whatever of the second. He states, however, that No. 2, as compared with No. 1, is more complicated and requires more assistance; but there is less stretching of the vessel wall, and he thinks there can be no possible narrowing of the lumen.

He also applies thin plates of magnesium, after suture, in partial injuries of the vessel wall.

JENSEN, in a research which was awarded a prize by the University of Copenhagen, gives a history of vessel suture, a list of cases performed clinically so far as he could find records up to the date of his publication, and a carefully tabulated account of his own experiments with various methods of union, both on veins and arteries.

In the union of divided arteries he used the U-suture, Gluck's and Murphy's Methods, and a cylinder modified after Payr's, which he made of ivory. His best results were with suture methods; in Murphy's Invagination method he found a tendency to narrowing of the lumen.

In the union of veins he used the suture most successfully; Payr's magnesium cylinder, and cylinders made of bone, and decalcified bone, with poor results.

His own method of suture which he recommends is a continuous suture through all the coats of the vessel, after the preliminary inser-

tion of two or three U-sutures to hold the vessel ends in place. He criticizes adversely the use of any kind of apparatus, thinks them more difficult to apply, and liable to cause thrombosis or narrowing of the lumen, the former possibly due to the irritation of an unorganized body of such length on the outside of the vessel wall.

He considers the principal cause of thrombosis after vessel suture is infection, and that the presence of an uncovered piece of suture in the lumen of the vessel is unobjectionable and does not lead to thrombosis.

Reinsholm also prefers suture methods to mechanical supports, and thinks that a method by which intima and intima are brought together is best for veins, and may also be good in many cases, especially of the smaller arteries. With larger arterial trunks he prefers Murphy's method.

Höpfner, working with Payr's method, had success in transplanting pieces of artery from one animal to another of the same species. He examined his cases at periods varying from thirty-nine to ninety-one days after the operations were done. He found the wall of the transplanted piece somewhat thickened, but the lumen of normal width, intima smooth, edges at position of union even, and nowhere thrombus, or its organization products.

In attempting to insert a piece of vein be-

tween the ends of the divided artery of the same animal, he had always thrombosis in eight to ten days, and in still shorter time in his attempts to transplant artery from another species of animal. The graft in this latter case was also remarkably quickly absorbed.

It is, however, to be noted that CARREL and GUTHRIE have successfully implanted a piece of vein between the ends of a divided artery in a dog. They used a suture method.

STICH, MAKKAS, and DOWMAN have done very successful circular unions of arteries by a method of first putting in three traction loops at exactly equidistant places in the circumference of the vessel, perforating all the coats. The vessel ends being thus held in apposition, and the circumference rendered by traction on the loops three-cornered, an ordinary continuous suture is run round the vessel. The method they describe as a development of Carrel's method, though it is very similar to the method recommended by Jensen, except that his two or three supporting sutures are of the U-suture type of Brieau and Jaboulay. They immersed their sutures, finest procurable silk, in liquid paraffin before insertion, and used finest English sewing needles. They have not only done successful circular unions, but have succeeded in transplanting cats' aorta into dogs' carotid with apparently permanent preservation of function.

The smallest vessel they have united was $1\frac{1}{4}$ mm. diameter, after division.

Amberg has attempted circular union of divided arteries in the carotids of horses and abdominal aorta of dogs, using a method by which each end of the divided artery was split a little way up each side, the two halves of the wall being everted, and sutured to the corresponding piece on the other end of the vessel, bringing intima to intima. He had poor results, sometimes hæmorrhage, sometimes thrombosis, with partial or complete obstruction of the vessel lumen.

Exner, using Payr's method, failed in the attempt to implant vein between the ends of a divided artery, and always met with thrombosis.

Chérie Lignière thinks all methods of circular union difficult, and recommends Payr's as the best. He found the cylinders absorbed after twenty days, and considered their presence exerted no unfavourable effect on the healing process. Union begins after twelve hours, and though a thrombus may form, it does not necessarily exert any unfavourable influence on the healing. He states, however, that though the method prevents fear of primary hæmorrhage, it does not preclude secondary hæmorrhage.

Tomaselli, working at Salomoni's Institute, thinks the method of union by laying intima to intima and suturing is easiest, quickest, and best safeguards against hæmorrhage. There is

no fear of narrowing of the lumen as there is in invagination, and very small risk of aneurysm. He states that the histological appearances at the site of union are almost perfect, but that the internal elastic lamina is not regenerated. There is hypertrophy of the muscular and elastic layers at the edge of the suture.

Da Gaetano, after reviewing the history of vessel suture, gives his own method. He uses a round needle, finest silk, and does not perforate the intima. He inserts a small spindle-shaped glass bobbin between the two ends of the vessel to be united, pushing the vessel wall over the narrow ends of the bobbin, for convenience of inserting the suture, which is a continuous one. Before drawing the suture tight the bobbin is slipped out between the loose stitches. Results good functionally, and microscopically he found in three to four months a new formation of muscle and elastic fibres in the scar.

Sweet has published a discussion of the technique of vessel suture. He thinks there are other causes of thrombosis after operation than sepsis, since a thrombus may form immediately on allowing the circulation to be restored, before sepsis has had time to act. He considers the possibility of ferments present in the tissues fluids, issuing from the cut edge of the vessel wall, causing the blood to clot ; and also points out that the presence of a suture

interferes with the natural expansion and contraction of the vessel wall, causing a fixed point where clot may form. He thinks success depends chiefly on the manual dexterity of the operator, and that he who is capable of attention to the minute details of asepsis required in these circumstances, is also capable of acquiring the manual dexterity necessary.

Watts has had very successful results in circular unions by Carrel's method, having thirteen successes in as many operations on the carotid artery in dogs, and two failures in the case of the femoral artery, due to infection and thrombosis. He insists, like all other workers, on a strict aseptic technique, and thinks thrombosis might be caused by minor degrees of infection, which were, however, insufficient to prevent primary healing of the wound.

Payr has hotly protested against the criticisms of Jensen, Reinsholm, Salinari and Virdia upon his methods of vessel union, accusing them of not truly following his method of procedure. He especially cites Höpfner's work in support of his method.

With regard to the circular union of blood vessels in human surgery, up to the present very few cases have been reported.

Murphy has used his method twice in the union of divided arteries, both times for injury following shot wounds. In one case, eighteen

days after the injury, $1\frac{1}{4}$ cm. of the femoral artery was resected, and the union effected. In the other $\frac{5}{8}$ cm. of vessel was resected three days after a revolver wound of the shoulder, with immediate restoration of the circulation.

Both cases were regarded as cures, but in the second no radial pulse could be demonstrated two months after the operation. There was, however, in neither case any circulatory insufficiency in the limb affected.

KÜMMELL sutured the femoral artery in a woman from whom he removed a malignant growth of the thigh involving the vessel. He resected 4 to 5 cm. of the artery, invaginated central into peripheral end, and sutured it with finest silk, not piercing the intima. He had to acutely flex the knee and hip joints to do this. The result was apparently good. Four months later the patient returned with a local recurrence of the tumour, and died. Post-mortem the artery was filled with new growth, and thrombosed up to the iliac artery, which condition Kümmell considered to be secondary to the invasion of the vessel by the growth.

DELANGLADE united by suture the radial and ulnar arteries one finger's breadth below the division of the brachial. Immediate restoration of the circulation occurred, and healing ensued in spite of infection. Later the radial pulse was absent, but Delanglade thinks the case was successful.

Payr claims to have performed the first circular union of a vein, and Kümmell has also reported a successful case. Payr's case died in three days of lobular pneumonia, and the vessel (femoral vein) was at the autopsy free from thrombus.

SECTION III

In the majority of cases of artery suture success can never be definitely certain unless a subsequent examination of the site of suture is available.

The immediate restoration of the pulse in arteries arising from the sutured vessel is only proof of the immediate restoration of the blood flow at the point of union : if the pulse persists permanently, it may be due either to complete and successful union of the injured vessel, or to the formation of an efficient collateral circulation ; if the pulse, on the other hand, disappears subsequently, it probably indicates complete thrombosis, or possibly extreme narrowing of the lumen at the suture site.

The conditions of success in the suture of blood vessels must be : Retention of the lumen of the sutured vessel at or nearly at its normal width, extreme narrowing or obliteration being failure.

In the cases of union of completely divided arteries reported clinically, none appears to have been unquestionably successful.

Post-mortem observation in the cases of union of divided veins is not available in Kümmell's case, and in Payr's was only three days after the operation, rather too early to judge of permanent results.

Cases adjudged failures from the standpoint above laid down have at least the merit of allowing time for a gradual and more efficient formation of a collateral circulation, while greatly reducing the risk of gangrene of the limb, as was pointed out by V. Horoch.

The chief dangers connected with artery suture are :—

Hæmorrhage,
Sepsis,
Thrombosis,
Aneurysm.

HÆMORRHAGE was a great difficulty to the earlier pioneers of the proceeding. With the use of round fine needles, suture material which completely fills the needle holes, and the avoidance of too tight tying, and so of cutting

through the vessel wall, this danger has been much diminished. Murphy's and Payr's methods would appear to most certainly preclude the possibility of hæmorrhage. Chérie-Lignière, however, who has used Payr's method in preference to any other, says that, while absolutely preventing primary hæmorrhage, it does not preclude the possibility of secondary.

Sepsis is tantamount to failure. In no department of surgery is a perfect aseptic technique more essential. Apart from the risk of pyæmia, some observers, notably Clermont and Jensen, consider sepsis to be the chief cause of thrombosis. It might also easily lead to secondary hæmorrhage, and a septic thrombus would at any rate certainly cause permanent occlusion of the vessel.

Thrombosis is perhaps the greatest risk to be run. The causes which lead up to it are variously considered by different authors. Jassinowsky considered the presence of suture material protruding into the lumen to be one of the chief causes, and so recommended that the suture should only penetrate the two outer coats of the vessel. Murphy held the same view, and in his method of union has tried to prevent the suture from projecting into the lumen. Reinsholm apparently holds the same opinion, and has followed Murphy's procedure in some of his experiments; otherwise he recommends the apposition of intima to intima. Payr, in-

fluenced by the same idea, has endeavoured to avoid sutures altogether by the use of his apparatus, and has been followed by Höpfner, Exner, and Chérie-Lignière and others. Jensen and Reinsholm, however, object to Payr's method that it necessitates the separation of so much vessel wall from the surrounding tissues as to interfere with its nourishment, and further consider the presence of the magnesium cylinder itself to be a cause of irritation, both these factors tending to the formation of thrombus.

Brieau and Jaboulay, also Salamoni and Tomaselli, have tried to avoid the presence of suture material in the vessel lumen by the special method of union by means of the U-suture, bringing thereby intima to intima, and a very minimal extent of suture impinging upon the lumen.

Amberg also experimented with a modification of this suture method.

On the other hand, Clermont and Jensen particularly cite sepsis as the chief or only cause of thrombosis, and think the presence of suture material in the lumen is not objectionable.

Jensen, in his excellent paper, has published most detailed reports of his cases, and has moreover tried a greater variety of methods than any other single experimenter. I have made some calculations from his tabulated results, as follows :—

On both arteries and veins, there were altogether thirty-five experiments, of which, in eight cases, the animal lived less than a week. Discarding these eight as inconclusive, there remain twenty-seven: of these—

Sixteen thrombosed.

Eleven remained patent (three very narrowed).

Eight of the twenty-seven cases were examined bacteriologically, of which—

One of the eleven patent had microbes in the silk.

Ten of the eleven patent seem not to have been examined.

Seven of the sixteen thrombosed had microbes in the ligature or thrombus.

Nine of the sixteen thrombosed seem not to have been examined.

Nine of the twenty-seven cases were united by means of mechanical apparatus (Payr's, or modifications of it), of which—

Two successful = 22·2 per cent.

Five thrombosed = 55·5 per cent.

Two very narrowed = 22·2 per cent. (unsatisfactory).

Thirteen of the twenty-seven cases were done by a suture method with no suture impinging on the lumen (Murphy's, Gluck's, U-suture), of which—

Five successful = 38·46 per cent.

Eight thrombosed = 61·54 per cent.

Five of the twenty-seven cases done by Jensen's Method (two or three interrupted U-sutures, and a continuous suture through all the coats), of which—

One successful = 20 per cent.
Three thrombosed = 60 per cent.
One very narrowed = 20 per cent. (unsatisfactory).

This analysis of Jensen's results does not show sepsis as the only cause of thrombosis. Readily admitting that sepsis nearly always causes that condition, there still remains the probability that the presence of free suture material in the vessel lumen acts also as a very important cause : the percentage of successes is greater where the suture material does not invade the vessel lumen. The latter method shows the smallest percentage of successes of the three divisions. It is true the actual number of cases in any division is not enough to draw definite conclusions from, but they are sufficient to suggest that there are other causes of thrombosis than sepsis.

Aneurysm, all experimenters agree, as being a rare sequela of artery suture. One case, in human surgery, illustrates the possibility well ; that is Ssabanjeff's.

His patient had occlusion of the femoral artery by an embolus, and threatening gangrene of the limb. He conceived the idea that,

if he could remove the embolus and suture the vessel, the danger of gangrene might be averted. He, therefore, exposed the femoral artery, vein and the saphena vein, opened the artery and intended to inject normal saline solution into it and watch for its return by the veins, which would indicate freedom of the circulation. At this stage the patient became so ill that he abandoned his idea, and proceeded to amputation of the limb. It was not, however, necessary to amputate so high, so he sutured the wound in the artery by means of fine silk sutures involving the media and adventitia only, and did the amputation lower down. The patient died nineteen days later, and post-mortem examination of the sutured blood vessel showed the following: "Intima edges gaping somewhat, and a dark brown spindle-shaped clot 1¼ cm. long and 3 mm. thick clinging to the vessel at this point. Adventitia had united. Microscopically a wedge of round-celled infiltration lay between the edges of the intima and media; passing into direct communication with the thrombus."

There thus appears to be a distinct possibility of an aneurysm forming in this case had the patient survived. This danger is probably much diminished by sutures perforating the intima. Many observers, however, fear the perforating suture as a powerful cause of thrombosis.

Weighing the various methods of vessel

suture, the dangers of each, and the requirements of the case, it seems that a suture which will pierce all the coats of the vessel, but will not project into the lumen, best fulfils the necessary conditions.

The use of mechanical apparatus has only been made by a few experimenters, and while showing a great amount of ingenuity in overcoming the objections to a suture, the bulk of opinion seems to be against them, on account of their being somewhat complicated in use, and necessitating the presence of a foreign body, which, even though it is absorbable, is for a time a source of irritation to the tissues and excessive reaction, which is of itself undesirable, on their part. Moreover, they are obviously inapplicable in the case of it being necessary to unite a blood vessel which had branches in the immediate neighbourhood of the seat of union, on account of the length of the instrument itself. Also, since so many sizes of cylinders must be kept ready to hand, often it would happen, especially in rendering immediate aid in cases of accident, that the necessary appliance was not to hand when wanted.

A further objection to the use of both the cylinders, and of Murphy's suture method, is that in cases where a considerable piece of artery or vein had to be resected, the amount of vessel wall utilized either in invagination, or in reflecting over the cylinder and subsequent in-

vagination, might entirely preclude the possibility of bringing the ends together and uniting at all, or only at the risk of a great amount of tension. This objection also applies to Gluck's method, unless the cuff were provided elsewhere than from the vessel concerned, whereas if a cuff of rubber or decalcified bone were used, the objection cited above to the presence of a large foreign body would here also apply.

The suture which appears best to fulfil the conditions necessary is the U-suture of Brieau and Jaboulay, which has also been successfully used by Salomoni and Tomaselli. Jensen himself, who has tried a greater variety of suture methods than any other single observer, says that few attempts have been made with this method, but the results gained promise much.

My own experiments have, therefore, all been done by some method having the U-suture as its foundation, the immediate object having been to examine the processes leading to healing of wounds in blood-vessels, and also to perform a series of experiments from the surgical point of view, to establish a method of suture which would, as far as possible, overcome some of the difficulties met with in these operations, and at the same time to be independent of special apparatus for the purpose.

With regard to the method of uniting the wounds in the vessel, the object aimed at in

every case has been that of bringing the two endothelial surfaces together. The sutures have always perforated all the coats of the vessel, but by bringing endothelium to endothelium, by means of a U-suture, or mattress suture, or the further developments of these underlying ideas in my later cases, the minimum of bare suture was exposed in the vessel lumen.

Experiments I, II, and III were done to see whether the mere presence of suture material, either silk or chromic gut, would cause thrombosis of the vessel. The results showed that neither in twelve hours, two or four days did complete thrombosis occur, but that the surface of the suture material was rapidly covered by a small thrombus which seemed to prevent further thrombosis by keeping the blood from contact with the foreign body.

Experiments IV to XVII were all done by means of a mattress suture; this is tantamount to a continuous U-suture, the U's being with their convexities alternately on the one and on the other side of the wound. The objections to it, in the case of longitudinal wounds were: (1) A tendency to sag in the middle part of the wound, which consequently gaped slightly, and required one or two supporting sutures to prevent it (*vide* Experiments VI, VII, IX). (2) A tendency for the suture to cut through, towards the margin of the wound (*vide* Experiment VI). This was also very marked in circular

unions by this suture (*vide* V, X, XI, XII), no doubt due to the constant cutting of the unyielding suture with each pulsation against the expanding wall of the vessel.

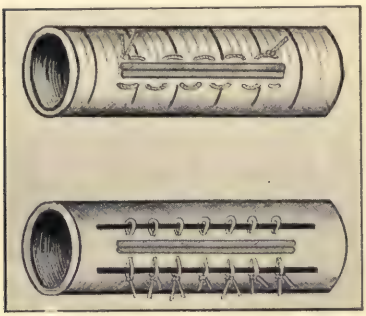


FIG. V.—Author's method of Suture of Longitudinal Slit in Vessel Wall.

1. Mattress suture.
2. Adaptation of quill-suture, with strand of chromicized catgut for the quill.

Experiment XVIII shows a transition stage in the method of suture. While being still a continuous suture of the mattress type, a slip of chromicized catgut was laid on each side of the wound in the vessel wall, and the suture passed over it, the chromicized gut acting as a support between the points of suture, and as a preventive of the tendency for the suture to cut through the wall of the vessel.

Experiment XX exhibits the final method of suture for the joining of longitudinal wounds in a vessel. Up to this time I had used finest sewing needles, either straight or half-curved. Now I had a special needle made, almost as fine as the finest sewing needle, but in a handle, the needle being slightly curved, and the eye placed at the junction of the bend with the straight part. The sutures were all passed before any were tied, and as the point of the needle

carrying the suture was passed through the two sides of the divided vessel wall, the loop of the suture was seized and held by a fine pair of forceps and the needle withdrawn, leaving a double suture laid, the two joining by a loop which was temporarily passed over a probe. All the sutures being laid, a piece of chromicized gut was drawn through the loops, which were then drawn tight, the ends being tied successively over another piece of gut on the other side of the wound in such a way that the thread which formed the deeper part of the loop round one piece of gut formed the superficial part round the other, so forming a figure ∞ in transverse section of the vessel at the point of suture, as shown in the illustration, and thus making the narrowest possible amount of suture at the point of piercing the

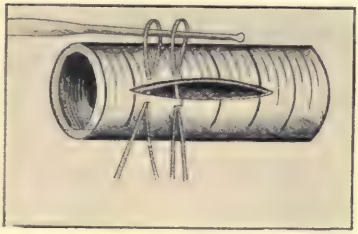


FIG. VI. Author's method of Quill-suture. Loops of suture temporarily threaded over a probe.

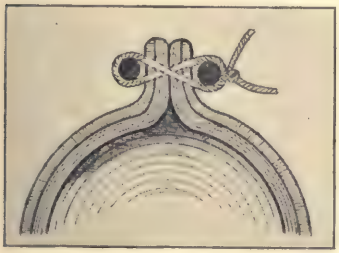


FIG. VII. — Author's method of Quill-suture. Transverse section of vessel with suture in situ, showing apposition of endothelium to endothelium, the position of the chromicized catgut "quills," and the figure of 8 formation of the silk suture.

vessel-wall; the gut preventing a tendency of the silk to cut through, and giving a support and pressure between the successive points of suture. In fact, it resolved itself into what is known as a quill-suture, the quill being represented by chromicized catgut.

The method of end to end union of a divided vessel finally adopted was similar to that described above for union of longitudinal wounds, only for the necessary added difficulties due to the contraction of the vessel when empty. The first seven circular unions made were done in the following manner.

First, three U-sutures were inserted at equidistant points in the circumference of the vessel, penetrating all layers of the vessel wall, and were tied. No. 000 silk was used as suture material, the free end of the tied U-suture being utilized as a traction thread, and the other end, armed with a half-curved finest sewing needle, being used to lay a mattress suture to the next U-suture, to the free end of which it was tied. The result, as regards the immediate effect of the suture, was always satisfactory, the circulation being at once restored, and practically no oozing occurring at the point of union, the expansion of the vessel when filled with blood drawing the suture tight, and so preventing leaking. In Operations V, X, XI, XII, the suture cut through, the ends of the vessel being in each case found some weeks

later thrombosed, and separated by about a centimetre. In all these four, however, about one centimetre of vessel wall had been excised, containing the union of a longitudinal cut into the vessel previously made. In Operation XIII the dog died of pneumonia on the ninth day, and the vessel was thrombosed. Probably there had been septic infection in this case. In XV the dog died of pneumonia on the second day, the vessel not being thrombosed. In XVI and XVII the dog died of encephalomalacia on the third day, both vessels being thrombosed. Thus, of the first eight circular unions made, four cut through, two dogs died of pneumonia, in one of which was no thrombosis, but the animal only lived two days, not long enough to pronounce upon the result of the operation, and in the remaining case in which circular union was done on both carotids the same day, the dog died of encephalomalacia, due to thrombosis occurring in both carotids. These results were, therefore, so unsatisfactory that I sought for a modification of my method, especially with the idea of preventing the suture cutting through. This I found in the application of the quill-suture method, modified for the special circumstances of transverse division and end-to-end reunion of the vessel from what had been suitable for a longitudinal wound in the vessel wall.

For the purpose of effecting this, I used the

special needle depicted, and had a small instrument made, consisting of a flat piece of metal with three or four notches cut at each end for the purpose of holding a thread pressed into it tightly, and graduated along the middle in centimetres and fractions of centimetres. The method of suture was as follows :—

The carotid being laid bare, the sheath and adventitial tissue being divided longitudinally with fine scissors, and separated by blunt dissection from the vessel wall, the little measure above described was slipped under the vessel before the clamps were applied, and the outside diameter of the vessel noted. The clamps were then applied above and below the proposed site of division, and the vessel cleanly divided with scissors.

The first suture was inserted on the deep aspect of the vessel by means of the special needle threaded with finest silk, first from without inwards through one end of the divided vessel, and then from within and through the other end, about 1 to 2 mm. from the edge. The loop was seized with forceps and the needle withdrawn. A piece of chromicized catgut and a thread of silk were then slipped through the loop, which was drawn tight, and tied in the figure 8 manner over another piece of chromicized gut. The long ends of the suture and the piece of silk inserted in the loop were used as traction threads on the same side

of the vessel, one for each fragment, so as to equalize the traction on the two lips of the wound. The second suture was inserted diametrically opposite the first, but was not yet tied, the loop of it being drawn well through. The loop and the free ends were used as the traction threads on the other side of the vessel.

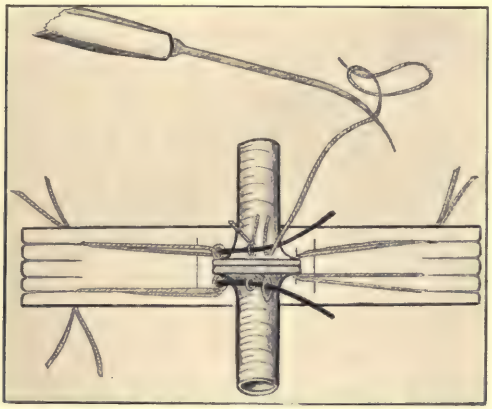


FIG. VIII.—Author's method of Quill-suture applied to the End-to-end Union of a divided Vessel. Actual size.

The traction loops were fixed in the notches of the little measure, stretching the vessel laterally to such a degree as to make it extend 1½ times the diameter of the artery noted before division of the vessel, when full of blood. According to the number required, the sutures were then laid exactly as in the case of union of a longitudinal wound in the vessel wall, allowing 1½ mm. between the successive sutures, and tied over the "quill" of chromicized gut. One-

half of the vessel being then united, the traction loops were changed ends in the little measure, so bringing the opposite side of the vessel upwards. This was treated exactly like the first, in each case the sutures being laid in succession from the first laid and completely tied traction suture to the second laid and untied one. The two sides of the vessel being thus united, the second traction suture was drawn tight over both ends of the two chromicized gut "quills" and tied, the suture being thus completed. The result was a circular union, at a size of average distension of the vessel with blood. Of three unions made by this method Operation XXIII ended in thrombosis, the dog, however, having to be killed on the sixteenth day on account of rhinitis. XXVI ended in thrombosis, the dog being killed twelve weeks after operation. No. XXVII was satisfactorily united, and had almost no narrowing after fifteen weeks.

It is noticeable that there is practically no hæmorrhage on loosening the clamps after unions either of longitudinal slits, or complete circular division, by this method. Also the method appears to guard as much as is possible against the likelihood of the suture cutting through the vessel wall and so leading possibly to hæmorrhage, and in any case failure. The "quill" of chromicized gut both so supports the vessel wall between the sutures as to

render hæmorrhage in those places impossible, and also gives the sutures additional hold over a wider area of vessel wall, making cutting through unlikely, and fewer sutures necessary, consequently fewer punctures and less weakening of the walls of the vessel. The operation is undoubtedly difficult, but so is any other of the various methods devised for circular union of a divided vessel.

Another advantage of this method of union is that when complete healing has occurred, no suture material remains in the vessel wall *in situ*, the gut being eventually absorbed and the silk lying outside the vessel entirely. This can be seen particularly well in sections made from Operations XXII and XXVII.

One objection that may be made to the method as applied to longitudinal wounds of vessels, is that slight narrowing of the vessel is produced at the region of the wound. That is true, but it is very slight, only 2 to 3 mm. of vessel wall being sacrificed, and I do not think it is permanent, the vessel, even in a few days, appearing as wide in the region of the suture as elsewhere; and if permanent, it is hardly sufficient to make any practical difference in efficiency. Even in vessels the size of $\frac{1}{3}$ centimetre outside measure, when full of blood, the narrowing produced by insertion of this suture is inappreciable in extent and effect.

One thing I have not yet touched upon in my description of these operations, is the method adopted of clamping the vessels, to temporarily control the blood stream.

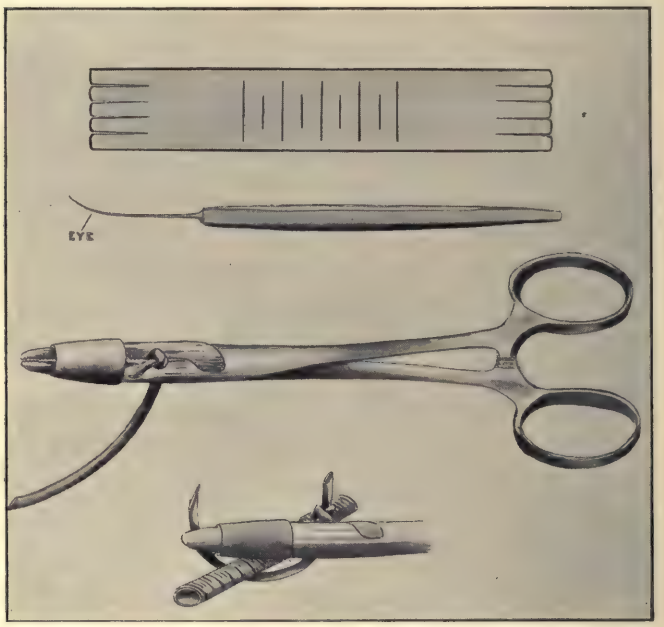


FIG. IX.—Instruments for Author's method of Quill-suture for Blood Vessels.

From above down—

1. The measure (actual size).
2. The needle (half actual size).
3. Clamp (half actual size) for temporary control of blood stream.
4. The clamp applied.

I devised a simple expedient which can be readily extemporized by anybody having pairs of thin-nosed compression forceps and a little fine red rubber drainage tube. A short length

of drainage tube is put over the two closed blades of the forceps, leaving a little of the blades near the pin and near the points exposed. Another rather longer piece of tube is then taken, and a knot made at one end. It is then passed between the blades of the forceps, between the rubber tubing and the pin, and the clamp is ready to use. To apply it, the longer piece of tube is passed under the vessel to be compressed, and brought between the tips of the blades of the forceps, being stretched to the required degree, according to the judgment of the operator, to control the blood stream, and the forceps are clamped. The vessel is thus held between the blades of the forceps, padded with a piece of tubing on the one hand, and a piece of stretched rubber tubing on the other. I have found this instrument quite satisfactory in use, and never to cause injury of the vessel wall where it is applied.

Sutures, whether silk or gut, have been sterilized by exposure to superheated alcohol vapour, Födl's apparatus having been used for the purpose. During the operations, after suture of the vessel was completed, the sheath was always united by a continuous fine silk suture, the deep fascia being also united by continuous or interrupted sutures, either silk or chromicized catgut. I regard this suturing in layers as important, both in supporting the wounded vessel during the healing process, and,

especially in animals, as helping to prevent the superficial infection of the wound, which is so common, from reaching the deeper parts and neighbourhood of the vessels.

Nearly all my operations were done without any assistance whatever. In performing a circular union assistance would be very valuable, and would materially tend to diminish the difficulties I met with in the course of the operation. In all cases iodoform collodion was used as a dressing.

Summary of Results

Longitudinal Wounds.

Total, 13.

Six mattress suture, of which—

One suture slipped,

One cut through,

both causing hæmorrhage; also one other had hæmorrhage but artery nevertheless healed.

Four healed with retention of lumen, time of examination after operation, three to nine days.

Two by mattress suture, only sutured over a slip of chromicized gut laid on each side of the wound.

One healed with retention of lumen, and died of pneumonia 11½ days after operation.

One (aorta) thrombosed, due, I think, to injury of endothelium, from difficulty of manipulation and want of assistance.

Five by quill suture.

All healed without thrombosis or narrowing, but one dog died in 36 hours of pneumonia, the others living from 9 days to 16 weeks.

CIRCULAR WOUNDS.

Total, 11.

Eight mattress suture.

Five, after excision of 1 cm. of vessel, of which:—

Four, sutures cut through and thrombosed.

One, died second day of pneumonia, not thrombosed.

Three thrombosed, no vessel wall excised.

Three quill suture, of which—

One, thrombosed.

One, healed and was satisfactorily united 15 weeks later.

One, partially thrombosed.

SECTION IV

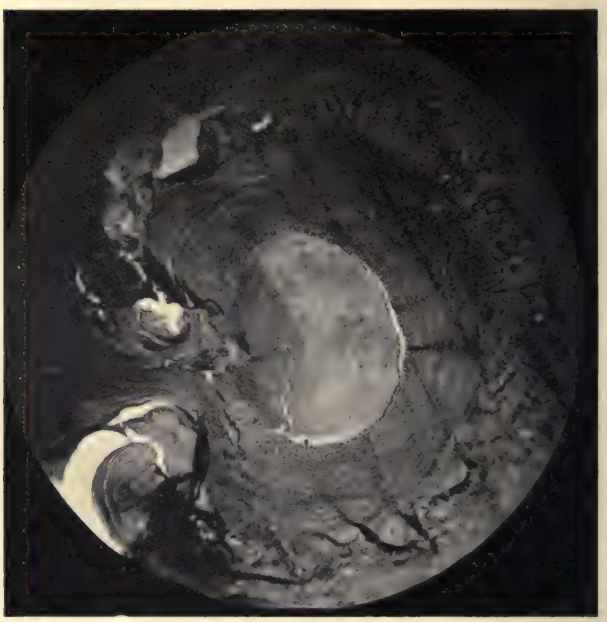
Histological Results

In order to avoid repetition, a description of chosen specimens only is here given.

EXPERIMENT IV (2½ days).—The wound in the vessel wall is closed by a wedge-shaped thrombus, the base of the wedge towards the lumen. The thrombus consists chiefly of fibrin. The endothelial lining in the thrombosed part of the vessel has disappeared. There is moderate round cell infiltration of the vessel wall near the suture. The portion of vessel wall between the sutures is devoid of nuclei (necrotic), only the elastic elements of the same being still capable of giving a special staining reaction.

EXPERIMENT VII (3 days).—(*Vide* Fig. 1, photo).—Osmic acid fixation. No fatty degeneration is visible in the endothelial protoplasm in the part occupied by the thrombus. The part of the vessel wall between the sutures as in Experiment IV. The necrosed part is separated from the lumen by the small throm-

bus. A layer of young granulation tissue around the periphery of the vessel.



Photomicrograph (Fig. 1).—Stained Osmic Acid, and Lithia Carmine.

Shows the small thrombus covering the portion of the vessel wall occupied by the suture. From a three days' preparation.

Experiment X (6 days).—The thrombus contains numerous cellular elements, some with regular round or spindle-shaped nuclei, others with irregular ones, which lie in spaces in the thrombus mass. The thrombus is commencing to organize and become absorbed. The elastic fibres at the position of suture begin to take

on a rather washy appearance under specific staining methods.

Experiment XXIV (9 days).—The endothelium completely covers over the thrombus, so that now the lumen of the vessel has again a complete endothelial lining. The thrombus contains no more red blood cells, but consists chiefly of structureless (homogeneous) fibrin masses, in which numerous fibroblasts are appearing. The elastic elements in the neighbourhood of the suture have disappeared. Young granulation tissue invades this necrotic area from without. (This case was one where a longitudinal wound of $\frac{1}{2}$ cm. long was sutured by only three sutures, and in which some oozing of blood occurred. In spite of this, the tendency to heal on the part of the tissues composing the vessel wall is strongly manifested.

Experiment XVIII ($11\frac{1}{2}$ days).—The thrombus appears completely organized, and converted into a wedge of young connective tissue. Over this is a continuous layer of endothelium. Under the endothelium, between this and the Elastica Interna of the original thrombus area is a little young connective tissue. Of the necrosed portion of the wall between the sutures now only the smallest remnant is to be seen. There is not a trace of fibrin to be seen in the young connective tissue which has replaced the thrombus.

Experiment XIV (13 days).—The endothelium lines the vessel lumen throughout (*vide* photo, Fig. 2. The endothelium is somewhat artifically detached from the neighbourhood of the scar). The site of the cicatrix is

Photomicrograph (Fig. 2).—Stained Hæmalum and Eosin.
Shows new formation of endothelium covering the young cicatrix. The endothelium has become artificially separated from the scar in the course of preparation. From a thirteen days' preparation.

occupied by numerous muscular elements, which in their arrangement are as yet markedly different from the physiological normal. No new elastic elements are as yet visible.

Of the thrombus, no more is to be seen. In

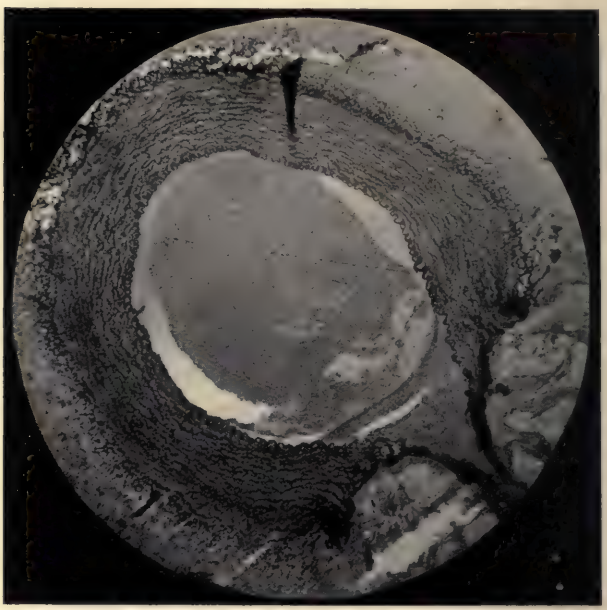
the parts surrounding the vessel together with the remains of hæmorrhage (which came perhaps from a subsequent oozing, but more probably from the soft tissues of the neck in the neighbourhood of the vessel being wounded by scratching) is extensive granulation tissue formation. Especially instructive is the preparation stained by Mallory's method, showing how the catgut is being penetrated by granulation tissue.

Experiment XXI (18 days).—Whereas the foregoing experiments were made with the mattress suture (with the exception of XXIV), the quill suture now comes into use. Therefore the original edges of the wound here lie in the most intimate contact, and the young connective tissue substituting the thrombus is reduced to a very small strand.

Corresponding to the suture site, in the immediate surroundings of the vessel, is a small quantity of hæmatogenous pigment in flakes among the connective tissue.

Experiment XXII (16 weeks).—The details of this specimen are especially interesting in the neighbourhood of the small triangular area (*vide* photo, Fig. 3) within which the thrombus was replaced by young connective tissue. Completely covered lumen-wards by endothelium, this tissue is distinctly separable into

two layers, an inner corresponding to the base of the triangle, an outer wedge-shaped piece whose apex stretches to the suture site; on each side this piece is bounded by the old

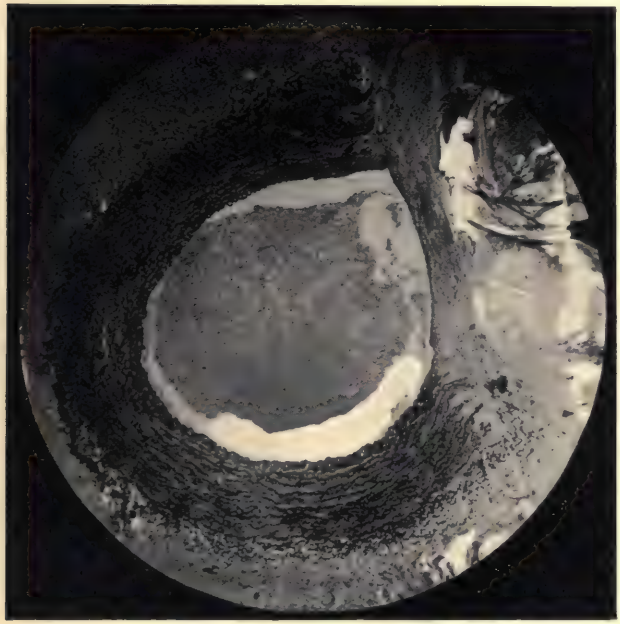


Photomicrograph (Fig. 3).—Stained Lithia Carmine and Weigert's Elastic Fibre Stain.

Shows firmly healed cicatrix, and the silk suture and chromicized catgut removed from the area of the vessel wall. The latter is largely absorbed. The specimen also indicates the close apposition of the walls attained by the use of the quill suture. From a sixteen weeks' preparation.

everted internal elastic lamina. The basal layer consists of a tissue already poor in nuclei and vessels; the outer triangular part of a connective tissue which, corresponding to the directions of its contained blood-vessels, still

exhibits the granulation tissue type. The inner layer, of the character of a young scar tissue, shows distinctly a cell and fibre arrangement parallel to lumen conture lined by the endothelium. The cell and fibre arrangement of



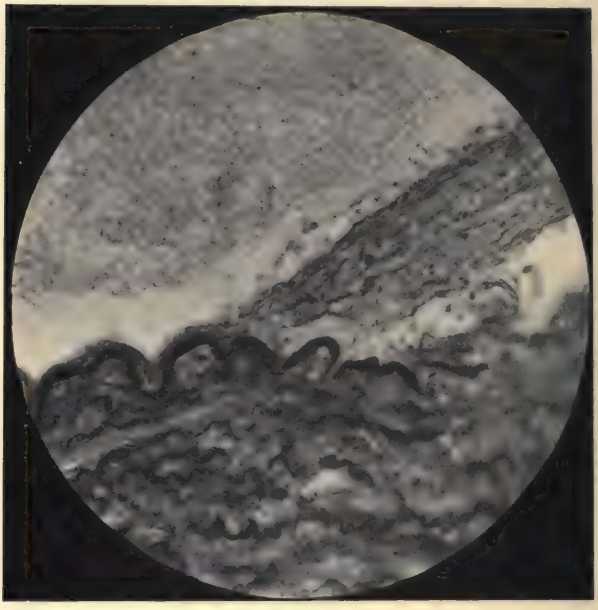
Photomicrograph (Fig. 3A).—Stained as Fig. 3.

This Section from the same preparation shows the same characteristics as Fig. 3, but shows a wider scar, being at a position where the silk suture penetrated the vessel wall.

the triangular portion is at right angles to that of the basal layer.

The cell masses of the basal part show a large number of elastic fibres of the smallest size. These appear to come chiefly from the

inner surface of the old inner elastic lamina, which curves away outwards towards the site of suture (*vide* photo, Fig. 4). The fibres lying next the endothelium appear a trifle less delicate than those of the outer layers. In



Photomicrograph (Fig. 4).—Portion of the same specimen as Fig. 3, highly magnified, to show the fine newly-formed elastic fibres in the cicatrix.

places the appearance is as though every single young connective tissue cell were surrounded by the delicate elastic fibrils.

As specimens stained by van Giessen's method show, the part nearest the lumen contains

young connective tissue fibres and also numerous muscular elements, which already exhibit their final circular arrangement.

In the granulation tissue of the outer portion both muscular and elastic elements are wanting.

The catgut is breaking up under the invasion of granulation tissue into irregular, often lumpy, and cleft fragments between which occasionally also foreign body giant cells are visible.

Experiment XXVII (15 weeks).—Longitudinal section through the site of a circular union. The microscopical examination shows a very similar condition to the foregoing. The new formation of elastic fibres, relatively stronger nearest the endothelium. Here again the new elastic fibres are exclusively to be seen in the inner part of the vessel wall (*vide* photo, Fig. 5, in one half). The relation to the old Elastica Interna is the same as in the foregoing case. The new muscle formation in the scar shows a rather further development. The latter here shows itself by a slight bulging lumen-wards, but only the slightest narrowing of the lumen is thereby caused. The remnants of the silk and catgut lie far removed from the vessel lumen, the catgut being for the most part absorbed.

Reviewing the histological changes in con-

Photomicrograph (Fig. 5).—Stained Lithia Carmine and Weigert's Elastic Fibre Stain.

Shows in longitudinal section of a case of end-to-end suture the same characteristics as Figs. 3 and 4 show in transverse secton of a longitudinal slit. From a fifteen weeks' preparation.

nexion with artery suture, as illustrated by the above described experiments, ranging from three days to sixteen weeks, the following may be briefly stated to be the course of healing :—

As the immediate result of the suture, necrosis occurs in the circumscribed portions of the wall, which are subject to the immediate pressure of the suture.

This affects all elements of the vessel wall,

only the elastic elements withstand more pressure than other tissues; at least they react longer to the special elastic fibre stain. By the necrosed area is enclosed a microscopically small and narrow cleft (in transverse section) which opens into the lumen of the vessel.

In the region of this cleft there occurs, obviously under the influence of the necrosis of the wall, some clotting of blood, of trifling extent. The thrombus is bounded towards the lumen by a flat surface, and scarcely narrows the lumen of the vessel. It consists of fibrin enclosing a small number of blood cells.

The assumption is justified that this thrombus acts as a preventive of hæmorrhage, whether caused by injury from without, or even in case of a suture cutting through.

From the end of the first week onwards, granulation tissue is already present round the vessel in the neighbourhood of the operation. Numerous newly formed capillaries, and fibroblasts, penetrate the suture area from without, not only the everted edges of the vessel and the suture material, but also the parietal thrombus. The fibrin masses are thus organized and absorbed, so that they are no more visible after ten days.

Already the endothelium has grown over the surface of the thrombus and furnished a complete endothelial lining for the vessels.

The further course of matters is the sub-

stitution of the young tissue in the immediate neighbourhood of the lumen of the vessel in two directions. First in the sense of disappearance of numerous small vessels, and second in that of the formation of new spindle-formed and fibrous elements in a direction parallel to the margin of the vessel lumen.

Eventually appears the new formation of specific tissues in the shape of *new formed elastic and muscular elements* in the young scar. These, three to four months after the operation, already present the same formation of layers as in the physiological condition, although the elastic elements especially appear only in the form of extremely delicate fibrils.

At this time the suture material remains only as a scanty remnant, obviously under the influence of the granulation tissue formed in the perivascular region which has pushed it relatively far away from the periphery of the vessel.

The results of the series of experiments are not so complete as I originally hoped. I lost valuable cases, on the one hand by epidemics of rhinitis and pneumonia among the dogs, and otherwise by infection, which is so frequently unavoidable in the after treatment of wounds in animals.

The specimens I have used to illustrate the course of healing of wounds in the wall of an artery are not all the result of one method of

suture. In actual fact three methods may be distinguished, yet the underlying principle of bringing intima to intima with a minimal amount of suture material exposed to the blood stream is common to all, and, in fact the methods are rather evolutionary stages of one technique than separate and distinct one from the other. The specimens, therefore, for purposes of microscopical examination may fairly be considered units of a continuous series.

Hitherto thrombosis, the danger of suture material cutting through, and hæmorrhage have been considered.

Now the question arises whether on histological grounds the operation of artery suture is justifiable, whether in any sense a *restitutio ad integrum* of the vessel wall occurs.

That question can, I think, be definitely answered in the affirmative. *Vide* my case at the end of the sixteenth week, Experiment No. XXIII, in which the scar, though readily distinguishable from normal artery wall, yet shows the unmistakeable presence of new elastic and muscle fibres, the whole being lined throughout by normal endothelium.

I think this satisfactory course of healing must be in part attributed to my adaptation of the quill suture method to the needs of artery suture. I would especially direct attention to the removal of the foreign body, in the

shape of suture material, from the area of the healing process. I think this is an important point, and unobtainable by other methods of suture.

But a final judgment respecting the healing process can be only arrived at when preparations from a still later stage are available for examination.

I do not believe that a thrombosis of microscopical dimensions can be avoided as a temporary phase of the healing process by any method of suture. On the other hand the examination of my own specimens has convinced me that such thrombosis is harmless, and even favourable to the healing process.

The impregnation of the suture material, which I agree with most other observers should be finest silk, with vaseline, liquid paraffin, or similar substances, with the end to prevent thrombosis, in my view is superfluous, and perhaps rather to be deprecated, as tending to delay, rather than promote, the healing process.

I absolutely agree with the views of those authors who hold that complete thrombosis is principally caused by infection. Exceptional occurrences, such as Jassinowsky's case of abscess in the wall of the aorta of a calf after suture, and Jensen's case of bacteria present in the silk, do not enfeeble this view. In my cases, Nos. XXI and XXV, of abscess without thrombosis, the abscess lay between the

skin and the deep fascia, and was obviously due to post-operative infection, and had probably not reached so deep as the vessel itself. They incidentally show the value, at least in animals, of suturing the sheath of the vessel and the deep fascia, as well as the skin.

The danger of aneurysm formation seems to me only to exist, judging from cases with considerable inflammatory lesions of the vessel wall, where the wall has been much weakened by the cutting through of sutures. Having regard to the new formation of elastic and muscular elements in the scar, I should regard aneurysm formation at a late stage of the healing process as almost impossible.

Cutting through of the suture can, I believe, be obviated by a careful choice of technique. It is, nevertheless, extremely desirable under all circumstances to avoid too great stretching of the vessel.

I am well aware of the incompleteness of the foregoing observations, but I consider that a large part of the unfavourable results were due to the method of procedure first employed. My failures, equally with my successes, are fully set forth in the tabulated results of my cases, so that others who may be engaged in similar research may be spared a considerable amount of fruitless work.

Perhaps I may myself, at some future date,

from further experiments in the same direction, give a complete microscopical account of what I have so scantily at present succeeded in portraying.

Finally, I must tender my utmost thanks to Professor J. Hochenegg, Director of the second Surgical Clinic at the General Hospital, Vienna, also to his first Assistant, Dozent Dr. P. Albrecht, for their goodness in allowing me every convenience for conducting my experiments in their Animal Operating Department.

Especially also am I grateful to Professor Oskar Stoerk, Assistant to the Professor at the Royal and Imperial Institute for Pathological Anatomy in Vienna, for his advice during the conduct of the work, and especially in relation to the preparation of the specimens, and the microscopical examination of the sections when made.

Number.	Animal.	Vessel.	Direction of Wound.	Method of Suture.	Course of Healing.	Length of Time.	Thrombosis ?	Result.
I	Rabbit .	Jugular vein	Transfixion	Chromic gut suture	—	12 hours	No	Death from exhaustion.
II	Rabbit .	Carotid	Transfixion	Chromic gut suture	No suppuration	48 hours	No	Vessel concerned removed.
III	Rabbit .	Carotid	Two transfixions	Silk, and chromic gut suture 2 cm. apart	No suppuration	96 hours	No	Vessel concerned removed.
IV	Bull terrier bitch	R. carotid, D. $\frac{1}{3}$ cm.	Longitudinal, $\frac{1}{2}$ cm. long	Mattress suture with finest silk	Hæmorrhage	$2\frac{1}{2}$ days	No	Vessel removed. Suture knot had slipped.
V	Same animal	R. carotid, D. $\frac{1}{3}$ cm.	Transverse	Excision of 1 cm. of vessel concerned in IV and end to end suture. Three U-sutures, and mattress sutures between	Superficial suppuration and much œdema	6 weeks	Vessel ends 1 cm. apart, both ends filled with soft thrombus	Vessel removed. Suture cut through.
VI	Mastiff dog	R. carotid, D. $\frac{1}{2}$ cm.	Longitudinal, $\frac{1}{3}$ cm.	U-suture each end and mattress between; a supporting continuous suture in middle on account of oozing, finest silk	Primary union	9 days	No	Large hæmorrhage on exposure, sutures cut through, clots extending down to pericardium. Dog died in anæsthesia.
VII	Bull terrier bitch	L. carotid, D. $\frac{1}{3}$ cm.	Longitudinal, $\frac{2}{3}$ cm.	As in experiment VI	Primary union	3 days	No	1 cm. vessel removed, and hardened in Osmic and Müller.

Number.	Animal.	Vessel.	Direction of Wound.	Method of Suture.	Course of Healing.	Length of Time.	Thrombosis ?	Result.
VIII	Fox terrier dog	R. carotid, D. $\frac{1}{3}$ cm.	$\frac{1}{3}$ cm. longitudinal	As in Experiment VI	Primary union, but much swelling	3 days	No	1 cm. removed. Large hæmorrhage had occurred, but vessel wound healing.
IX	Fox terrier dog	L. carotid, D. $\frac{1}{3}$ cm.	$\frac{1}{2}$ cm. longitudinal	As in Experiment VI, and a supporting suture in middle of wound	Dog scratched wound open whole length	6 days	No	1 cm. vessel removed, not exposed by scratching, which only opened down to muscles.
X	Bull terrier bitch	L. carotid, D. $\frac{1}{3}$ cm.	Circular union 1 cm. excised	As in V	Superficial suppuration	32 days	Vessel ends exactly as in V	Removed. Suture cut through.
XI	Fox terrier dog	R. carotid, D. $\frac{1}{3}$ cm.	Circular union, 1 cm. excised	As in V	Scratched open	27 days	Just as in V and X	Removed. Suture cut through.
XII	Same as XI	L. carotid, D. $\frac{1}{3}$ cm.	Circular union, 1 cm. excised	As in V	Scratched open, free hæmorrhage	24 days	As V, X and XI	Removed. Suture cut through.
XIII	Mongrel, Collie–St. Bernard	R. carotid, D. $\frac{1}{2}$ cm.	Circular division	As in V, X, XI and XII	Slight discharge of serum fourth day	9 days	Yes	Dog died ninth day of pneumonia.
XIV	Brown mongrel bitch	R. carotid, D. $\frac{1}{2}$ cm.	$\frac{1}{2}$ cm. longitudinal	As in VI	Like XIII, no suppuration	13 days	No	1 cm. removed.
XV	Same as XIII	L. carotid, D. $\frac{1}{2}$ cm.	Circular division	As in XIII	Normal	2 days	No	Died of pneumonia.
XVI	Same as XIV	L. carotid, D. $\frac{1}{2}$ cm.	Circular division	As in XIII	No suppuration	3 days	Yes	Died, encephalomalacia.

XVII	Same as XIV and XVI	R. carotid, D. ½ cm.	Excision of 1 cm. of vessel	As in XIII	No suppuration	3 days	Yes	Died, encephalomalacia.
XVIII	Mongrel fox terrier	R. carotid, D. ⅓ cm.	Longitudinal, ⅔ cm.	Continuous mattress suture, only each suture passed over a piece of chromic gut laid along each side of wound	Primary union	11½ days	No	Died, pneumonia.
XIX	Same as XI, XII	Abdominal aorta. D. ⅔ cm.	Longitudinal, 1 cm.	Exactly as in XVIII	Primary union	2 days	Yes	Died, paraphlegia.
XX	Same as XVIII	L. carotid, D. ⅓ cm.	½ cm. longitudinal	Three quill sutures, quill being represented by chromic gut, interrupted	Primary union	36 hours	No	Pneumonia, died.
XXI	Small collie	R. carotid, D. ·4 cm.	1 cm. longitudinal	As in XX	Abscess	18 days	No	Died, rhinitis and abscess.
XXII	Brown mongrel terrier bitch	R. carotid, D. ·4 cm.	1 cm. longitudinal	As in XXI	Primary union	16 weeks	No	Killed; vessel well healed.
XXIII	Small black mongrel dog	R. carotid, D ⅓ cm.	Transverse division	United by quill sutures	Primary union	16 days	Yes, partial	Dog killed; had been ill with rhinitis nearly all time after operation.
XXIV	Pomeranian	R. carotid, D. ⅓ cm.	⅓ cm. longitudinal	As in XX	Primary union	9 days	No	Dog killed.
XXV	Mongrel spaniel	R. carotid, D. ⅓ cm.	⅓ cm. longitudinal	As in XX	Abscess	17 days	No	Killed for pneumonia.
XXVI	Setter mongrel	R. carotid, dia. ⅓ cm.	Circular division	Quill suture as fully described.	Primary union	12 weeks	Yes	Killed and vessel removed.
XXVII	Black bull terrier	R. carotid, Dia. ⅜ cm.	Circular division	Quill suture as fully described.	Primary union	15 weeks	No	Killed and vessel removed.

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